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Dynamics of Femtosecond-Laser-Pulse-Produced Plasmas by e⁻ Thermal Transport in Transparent Solids

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Abstract

A plasma is created by 5×10^{14}W/cm intensity, 100fs laser pulsed irradiation of a transparent solid target. Time-resolved measurements of a probe light, interacting from both sides of the plasma, show the first direct evidence of a thermal transport driven supersonic ionization front.

Summary

This is a comprehensive report on both the experimental and theoretical studies, in an attempt to charracterize the importance of electron thermal transport. A series of pump-probe experiments using a trio of different targets is shown to demonstrate different physical effects and mechanims that regulate plasma formation and evolution. And more importantly, it experimentally proves that isolation of electron thermal transport is possible and confirms the first direct evidence of a supersonic ionization front.

The plasma is produced by irradiating a transparent solid target with

100fsec. pump laser pulses at a peak intensity of $5 \times 10^{14} W/cm^2$. The plasma is probed from both front and back sides of the plasma. Front and back side probings, offerring detailed measurements of plasma parameters, provide different but complementary information on plamsa evolution and energy transport mechanisms. Measurements of the plasma reflectivity, transmissivity and frequency shift of the probe light are obtained by varying the relative time between the pump and probe pulses arriving at the target surface. The glass target is amouphous (SiO_2) and contains a large amount of impurity materials. The fused quartz target is also amouphous (SiO_2), but contains a small amount of impurities. The coated target has an absorptive carbon film at the front surface. The film is 300Å thick and is used to enhance pump laser absorption at the surface.

The data by front-side probing shows no distinction for different targets. All data however indicate that a supercritical plasma layer is rapidly formed at the suface. The plasma remains highly reflective for the first few picoseconds, and undergoes expansion, which becomes significant after a characteristic time of ~6ps.

The back-side probe data taken with glass targets demonstrate formation of a large undercritical density plasma inside the bulk region behind the target by laser-induced collisional ionization. Such plasma is so absorptive that high reflectivity of the overdense plasma at the surface is blurred out, and that meaningful interpretation of electron thermal transport properties of the plasma is in vain. However, this finding may very well be a direct evidence for avalanche buildup of charge in laser-induced bulk damages that have been observed in a wide variety of optical materials.

The back-side probe data taken with quartz targets show effects of readily-ionized impurities and a strong competition between a highly reflective overdense plasma at the front surface and an absorptive underdense plasma in the bulk region behind the surface.

The back-side probe data for coated targets demonstrate elimination of the underdense bulk plasma, thus isolating the effects of e^- thermal transport. It shows that the plasma as viewed from the rear side has a long lived, steep density gradient. Comparison between the frequency shifts in the front- and back-side probes confirms that the plasma steep gradient is due to a electron thermal transport driven supersonic ionization front.

All these data will be shown and discussed in greater details together with an analytical theoretical model for propagation of a nonlinear thermal heat wave.

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